

New data on the origin and distribution of Western Australian sand fulgurites

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Abstract

Lechatelierite fragments totalling 1 084 g, part of a large sand fulgurite, have been recovered from Black Point, Western Australia. Black to very dark brown, altered, woody material plugged the lumen of many tubular fragments when collected. Finely macerated woody material from the fulgurite shows fibrous and cellular structure under the microscope, is anisotropic, and brown to orange. The mean refractive index of the woody material ranges from 1.574 ± 0.002 to 1.598 ± 0.002 , but most of it is close to 1.579 ± 0.002 . The evidence indicates that the Black Point fulgurite formed around a root. Whether this is a common mode of formation for fulgurites is still open to question, for roots are not necessary for the development of the tubular shape typical of fulgurites.

Lechatelierite tubes are also recorded from west Willetton in the Perth Metropolitan Area, and Mica Hill near Manjimup.

Sand fulgurites have now been recorded from the north of Western Australia almost to its extreme south, but their apparent concentration in the south-west is probably a function of population distribution. Fulgurites are likely to be found in all sandy desert areas of Western Australia, particularly in the north where lightning frequency is high.

Introduction

Sand fulgurites have been recorded from numerous localities in Western Australia, particularly in the south-west (Simpson 1931; Glover 1974, 1975). Most Western Australian fulgurites are represented by a few small fragments of lechatelierite (silica glass) and some by only one piece. Larger collections have been made in the Perth Metropolitan Area from Willetton (500 fragments, totalling about 100 g) and Beechboro (250 fragments, 92 g). The recent recovery of a fulgurite from Black Point (Fig. 1) is of special interest because it is made up of many large tubes containing altered woody material, evidently the remains of a pre-existing root. The possibility that sand fulgurites have formed around roots has been considered by several authors (Lewis 1936, Fenner 1949, Schonland 1964, Trendall 1964) but undoubted field evidence of genetic association has not been adduced. Another point of interest about the fulgurite from Black Point is the large weight of lechatelierite recovered, 1 084 g.

Fulgurite tubes from two other localities, namely west Willetton, and Mica Hill, near Manjimup, are recorded.

Lechatelierite from the Black Point fulgurite is stored in the Western Australian Museum (Nos. G13408 to G13410 inclusive) and the

Geology Department, University of Western Australia (Nos. 84672 to 84675 inclusive). Woody material from the Black Point fulgurite (No. 82871) and lechatelierite from the west Willetton fulgurite (No. 82872) are stored in the Geology Department, University of Western Australia.

The Black Point fulgurite

Microscopic appearance

The Black Point fulgurite was found on 20 March 1977 by Mr George Gardner, Mrs Linda Ronk and Mr Alan Ronk near the western edge of a sand blow-out 1 km north-east of Black Point (Pemberton 1:250 000 map, Series R502, S1 50-10, co-ordinates 354749). When in place it consisted of a fragmented tubular body branching downward into five main off-shoots which decreased in diameter with depth. The branches ended 4 or 5 cm below the waterlogged sand, that is, a little more than 1 m below the surface.

A few fragments from the tops of the branches are quite large. One flattened tubular piece with prominent flanges roughly parallel to its length is 20.5 cm long, up to 6.5 cm wide and about 1.5 cm thick (Fig. 2, left). Other fragments are not flattened in one plane, but are twisted rather irregularly (Fig. 2, right). Frag-

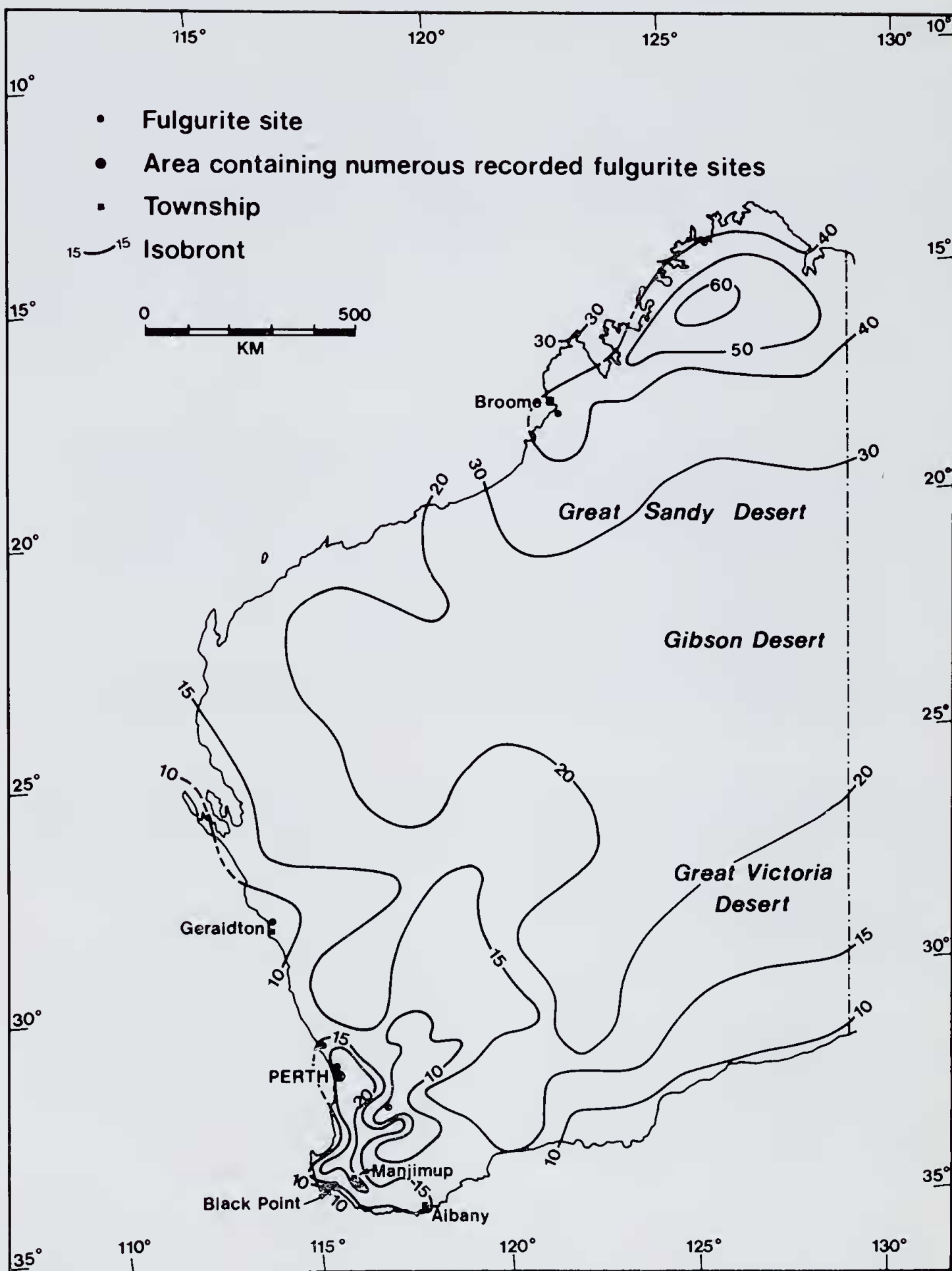


Figure 1.—Average annual thunder day map of Western Australia showing fulgurite sites. The large solid circle around Perth includes 9 separate fulgurite sites, and it is evident that fulgurite recovery is related to population density, and does not reflect the probable distribution of fulgurites. Isobronts after Commonwealth Bureau of Meteorology (1967).

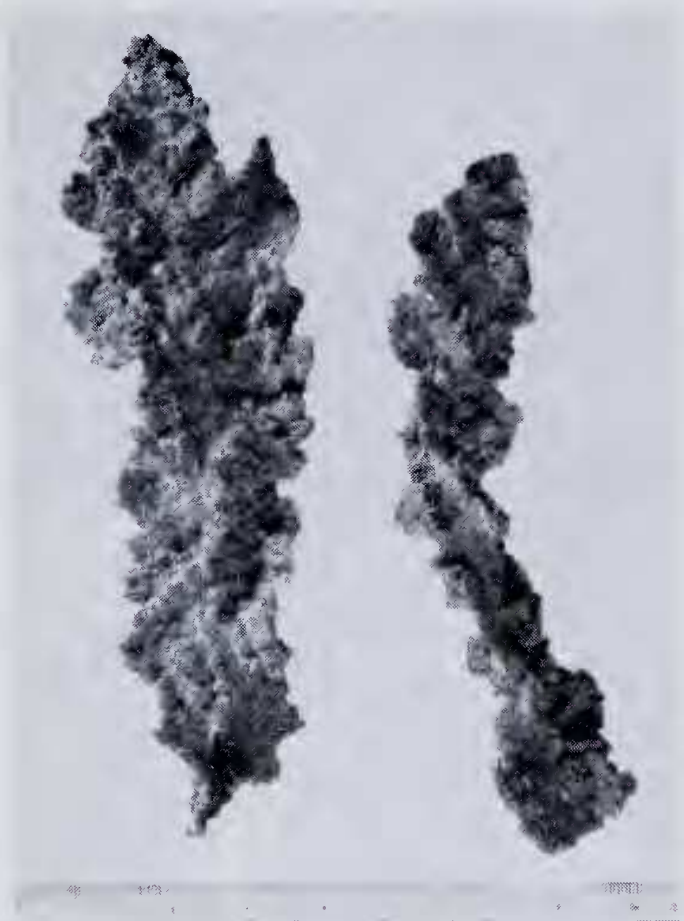


Figure 2.—Two large fragments from the top of the Black Point fulgurite. The fragment on the left is highly flanged, and is flattened in the plane of the photograph. The fragment on the right is flattened in several planes, as though twisted. Scale in cm.

ments from near the end of branches are thin and fragile, with numerous projections (Fig. 3). The inside of the tube, known as the lumen, is up to 1 cm in diameter in large fragments (Fig. 4), but is commonly flattened or triangular in cross-section. The tube walls of lechatelierite range from about 0.5 to 1 mm in thickness.

The rough, dull, outer surface of the fragments is made up of sand grains embedded in the glass, and contrasts with the shiny, smooth and somewhat mammilated glass on the inside. The outer surface ranges from very light grey (N8) to medium dark grey (N4), but is generally very light grey to light grey (N7) (See Rock-color Chart Committee 1963 for colour terms and accompanying numerical designation). Locally, the outer surface has orange or brownish hues, and material from the water-logged section is mainly very pale orange (10YR8/2) to pale yellowish brown (10YR6/2). The colour of the inner surface ranges from light grey (N7) to black (N1). The black or dark portions of the glass are irregularly shaped, range from less than 1 mm to several mm in diameter, and constitute about 30% of the glass. They commonly merge insensibly into the light grey glass.



Figure 3.—Fragile fragment from the bottom of a branch of the Black Point fulgurite. Scale in cm.

Microscopic appearance

Under the microscope most of the lechatelierite is colourless but there are irregularly shaped brown portions corresponding to the black material of the hand-specimen. The refractive index of the colourless glass is between 1.459 and 1.464 ± 0.002 , and is generally close to 1.461 ± 0.002 . Brown glass is commonly higher in refractive index, and some of the light brown (5YR6/4) glass is about 1.467 ± 0.002 . A few small, intensely coloured portions are harder to measure, but their index is higher still, and seems close to 1.475. Colourless and brown glass are both highly vesicular, with bubbles from 0.01 to 0.3 mm in diameter.

Sand grains embedded in the outer surface of the fulgurite are commonly partly coated with opaque mineral, apparently mainly iron oxide. Many grains are partly converted to glass: they are highly cracked on the outside, and commonly pass, via an altered, brownish, finely fibrous portion, into the glass of the fulgurite wall. This texture shows clearly that the fulgurite formed from fusion of sand grains.

Chemistry

The fulgurite contains little carbon, and a total carbon analysis by combustion on 1 g showed 0.01% C.



Figure 4.—Surface fragment of the Black Point fulgurite showing the lumen. Note the contrast between the smooth, shiny, black and grey inner surface, and the rough, dull, grey, exterior. Scale in cm.

Two black and two colourless portions of glass were analysed with the electron microprobe for SiO_2 , TiO_2 , Al_2O_3 , FeO , MgO , CaO and K_2O . One of the black portions recorded 1.93% TiO_2 and 0.66% FeO , and the other 0.14% FeO . Apart from SiO_2 , which virtually composes the remainder of the dark material, and forms practically 100% of the clear portions, no other oxide is present in more than trace amount.

Part of the fulgurite was crushed, and separated as far as possible by handpicking into dark and light portions. The separated portions were analysed by fusion (the method of Norrish and Hutton 1969) and comparison by XRF with USGS standards. Results for titanium and iron are as follows:

	$\text{TiO}_2\%$	$\text{FeO}\%$
Dark material	0.226	0.218
Light material	0.097	0.279

The combined microprobe and XRF results show that some dark areas are significantly enriched in TiO_2 , but the distribution and role of iron is uncertain. In general, the chemistry indicated by these partial analyses accords with what might be expected from Table 1, which shows that sand near the bottom of the fulgurite is mainly quartz (about 99.4%) with about 0.4% of the titanium-rich heavy minerals ilmenite and leucoxene.

Altered woody material

Sand and altered woody material were found in the lumen of tubes from all parts of the fulgurite. About 7 g of black to dusky brown (5YR2/2) woody matter were recovered for examination. A few of the pieces are 1 cm or more long and over 0.5 cm wide, and plugged the part of the lumen they occupied. They are unlikely to have fallen in, and therefore apparently preceded the fulgurite. The material is partly soluble in weak alkali, giving a brown supernatant liquid indicating the presence of humic acids.

Macerated woody material examined in oils under the polarizing microscope ranges from black and opaque, where coarse, through moderate reddish brown (10R4/6) to yellowish orange (10YR7/6) where sufficiently fine. Elongate fragments are commonly fibrous or have rather irregular structure, and some fragments are fairly homogeneous in appearance. A few pieces show well-developed cells from 8–13 μm in diameter, the cell walls being 1–1.5 μm thick. The material is anisotropic with low birefringence, and ranges in mean refractive index between 1.574 and 1.598 ± 0.002 , with most readings in the narrow interval between 1.575 and 1.583 ± 0.002 . These figures are toward the lower part of the range of 1.55–1.75 found by Pflug (1954) for lignite humites, and taken together with the presence of humic acids, seem to put the material near the peat-lignite boundary.

Petrography of surrounding sand

A sample of sand from around the bottom of the fulgurite was sieved and weighed. The sand is medium-grained ($M=0.28$ mm), fairly well sorted ($So=1.37$), and consists mainly of quartz. Most grains near the median size are rounded, according to the terminology of Pettijohn (1975, p. 57).

About 95% of the quartz grains are clear, the remainder being cloudy because of numerous minute indeterminate inclusions. Some of the clear grains contain inclusions of opaque mineral, zircon, or tourmaline. The mineral weight % of the sand, obtained from combining grain counts of the weighed size fractions and separated heavy minerals, is shown in Table 1. Three hundred grains from each fraction were counted. Heavy minerals, of which ilmenite is the main constituent, make up only 0.4% of the sand.

Table 1

Weight % of minerals in sand near the bottom of the Black Point fulgurite

Mineral	Weight %
Quartz	99.38
Ilmenite	0.35
Kaolinized feldspar	0.20
Leucoxene	0.03
Zircon	0.02
Magnetite	0.01
Rutile	Trace
Sillimanite	Trace
Kyanite	Trace
Tourmaline	Trace
Staurolite	Trace
Unknown	Trace

The west Willetton fulgurite

The west Willetton fulgurite was found by Mr R. H. Stranger in a road cutting through sand along Agin Court Drive (Pinjarra 1:250 000 map, series R 502 51 50-2, coordinates 386035). It is a tube 3.0 cm long, with an irregularly shaped, very roughly circular cross-section, ranging in diameter from 0.9 mm to 1.3 mm. Wall thickness ranges from about 0.5 mm to 1.0 mm. The rough, outer surface of the tube is white (N9) to very light grey (N8) and contains embedded, partly fused white sand grains that are commonly rounded and about 0.25 mm in diameter. There are no prominent flanges. The surface of the lumen is shiny, fairly smooth to somewhat mammillated, and very light grey. About 20 small, irregularly shaped black portions up to 1 mm in diameter are scattered throughout the wall. The refractive index of the very light grey glass is 1.461 ± 0.002 .

The Manjimup fulgurite

The Manjimup fulgurite is recorded here to correct a published error of location. The fulgurite, CSIRO No. 9073, is a tube with an unusual lacy texture, and was submitted as coming from Wanneroo about 25 km north of Perth. It has already been described and illustrated (Glover 1975, p. 57). The object is now stated by W. M. McArthur (pers. comm. 1976) to have come from a sandpit at Mica Hill, about 14 km south-east of Manjimup, lat. $34^{\circ}19'S$, long. $116^{\circ}12'E$.

The origin of fulgurite morphology

The origin of lechatelierite previously found in sandy areas of Western Australia has been attributed to fusion of the sand by lightning (Glover 1974). The full argument will not be repeated here. It is enough to say that there are two Australian reports of sand fulgurites collected after observed lightning strikes (Simpson 1931, Fenner 1949, p. 128), and numerous extra-Australian reports (see for example Pfaff 1822, Wicke 1859, Van Bastelaer 1883, Diller 1884, Bayley 1892, Wood 1910, Noe-Nygaard 1973), and that all Western Australian lechatelierite fragments described have the same morphology and mineralogy as the bodies formed by lightning. All are either tubes, or fragments of tube walls or their flange-like extensions. It is still not clear, however, why sand fulgurites adopt a tubular habit.

Rock fulgurites are not recorded in Australia, and are therefore rather neglected in the local literature. Nevertheless, as they commonly take the form of glass-walled tubes within the rock, they should be considered in any argument about the origin of the tubular shape of sand fulgurites. Rock fulgurites seem to be found mainly on mountain peaks subject to lightning strikes. They have been described in a wide range of rock types, notably hornblende gneiss (Rutley 1885), glaucophane schist (Rutley 1889), and serpentine (Aston and Bonney 1896) from the European Alps; andesite from the San Francisco Peaks, Arizona (Davis and Breed 1968) and Little Ararat, Turkey (Switzer and Melson 1972); quartz diorite porphyry from Crested Butte,

Colorado (Switzer and Melson 1972); hornfels from Castle Peak, Colorado (Switzer and Melson 1972); trachyte from Nevado de Toluca in Mexico (von Humbolt 1845, reported in Davis and Breed 1968); and siliceous limestone from the Pyrenees (Diller 1884). They have even been reported from streets in Detroit (Hill 1947).

The presence of altered woody material within the Black Point fulgurite suggests that lightning followed down a small root and fused surrounding sand to form lechatelierite. The concept that roots have conveyed current in this way is not new, and has been considered for example by Lewis (1936), who described a fulgurite with an internal surface film of carbon, and by Schonland (1964), Fenner (1949) and Trendall (1964). Bushes or shrubs are quite likely to be struck by lightning, and live roots would be a better conductor than surrounding sand. Nevertheless, roots are not necessary for the development of tubular fulgurites. Some artificial fulgurites are tubular (Petty 1936; Fenner 1949; Schonland 1964) and a tubular sand fulgurite was recovered from a heap of building sand after it was struck by lightning (Van Bastelaer 1883). As mentioned above, many rock fulgurites are also tubular. Conventional theory attributes the lumen in sand fulgurites to thermal expansion of air or water, although a supposed mechanical action of the lightning in forcing the sand apart has also been suggested (see Frondel 1962). Vesicles are presumably caused by expanding gas or vapour. The very low amount of carbon in the Black Point fulgurite accords with the hypothesis that the sand was forced away from the root as it fused. Flattening and deformation of the lumen could be brought about by subsequent sand pressure on the plastic glass.

To sum up, the presence of altered woody matter in the Black Point fulgurite seems to be the firmest evidence found so far that a sand fulgurite has formed around a root. Whether this is a common mode of formation for sand fulgurites is still open to question.

Probable distribution of sand fulgurites in Western Australia

Most Western Australian fulgurites have been recorded from the populous south-west of the State, especially around Perth, and this almost certainly reflects the distribution of observers rather than fulgurites. The fulgurites are generally revealed in deflating areas, where wind has blown away sand and left the lechatelierite fragments.

One of the main factors affecting fulgurite abundance is the frequency of lightning, which is indicated cartographically by lines called isobronts that join places with an equal number of thunder-days in a given period. Nevertheless, isobrontic maps have not proved a reliable guide to the abundance of sand fulgurites, and it is worth considering why this may be. Thunder data are probably insufficient in many countries to produce reliable isobrontic maps, and it is notable that satellite data gathered on the world

distribution of some 7 000 lightning strikes in 1969-70 (Sparrow and Ney 1971) can be reconciled with the current isobrontic maps of some areas only in a fairly general way. However, there are certainly other factors. The thunder recorded on the maps includes an indeterminate proportion caused by cloud-to-cloud lightning, which is obviously irrelevant to any consideration of fulgurite formation. The age of the land surfaces, and the consequent period of their exposure to lightning are important, as are pronounced climatic changes in areas with long-exposed surfaces. The surface should be sandy and not shielded by a dense canopy of vegetation. Local conditions in sandy terrains can play a significant part: for example Lacroix (1931, 1942) emphasizes that Saharan fulgurites are only found near the base of dunes, where sand is moister than on the crest. Fulgurites may be less noticeable in some places because sand movement has broken them into small fragments, or because they are concealed under a growing sand cover. Whatever the combination of reasons, classical African fulgurite localities in the Sahara Desert (Lacroix 1931, 1942) and in the Kalahari Desert (Lewis 1936), show an isobrontic range from 40 to less than 10 (isobrontic data from the map of Griffiths 1972, p. 29). There is a similar situation in Western Australia, where recorded fulgurite localities show an isobrontic range from higher than 40 to less than 10 (isobrontic data from Commonwealth Bureau of Meteorology 1967). It seems that most sandy areas in Western Australia will yield fulgurites, and that they may be especially abundant in the thunder-prone northern areas of the Great Sandy Desert (see Fig. 1).

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